

BATH-HAVERHILL BRIDGE

(Haverhill-Bath Bridge)

Spanning Ammonoosuc River, bypassed section of Ammonoosuc  
Street (SR 135)

Woodsville

Grafton County

New Hampshire

HAER NH-33

*NH-33*

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FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD

National Park Service

U.S. Department of the Interior

1849 C Street NW

Washington, DC 20240-0001

# HISTORIC AMERICAN ENGINEERING RECORD

## BATH-HAVERHILL BRIDGE (Haverhill-Bath Bridge)

HAER No. NH-33

LOCATION: Spanning Ammonoosuc River, bypassed section of Ammonoosuc Street (SR 135), Woodsville, Grafton County, New Hampshire  
UTM: 18.736980E.4893309N, Woodsville, VT-NH Quad.

DATE OF  
CONSTRUCTION: 1829

STRUCTURAL  
TYPE: Town lattice truss

DESIGNER/  
BUILDER: Unknown

PRESENT OWNER: Town of Bath and Town of Haverhill

PREVIOUS USE: Public road bridge until 1999

PRESENT USE: None

SIGNIFICANCE: Bath-Haverhill Bridge is the oldest existing Town lattice truss, and one of the oldest covered bridges in the county. The Town lattice truss was one of the most widely used wooden truss forms. The bridge was in service for 170 years. Until bypassed in 1999 it carried the traffic of a numbered state highway.

AUTHORS: Joseph D. Conwill, Editor, *Covered Bridge Topics*, July 2002  
James L. Garvin, August 21, 2002  
Francesco Lanza, Engineering Technician, July 2002

PROJECT  
INFORMATION: The National Covered Bridges Recording Project is part of the Historic American Engineering Record (HAER), a long-range program to document historically significant engineering and industrial works in the United States. HAER is administered by the Historic American Buildings Survey/Historic American Engineering Record, a division of the National Park Service, U.S. Department of the Interior. The Federal Highway Administration funded the project.

**CHRONOLOGY**

1784	Birth of Ithiel Town
1820	Ithiel Town patents the Town lattice truss
1826	First discussion of a road to the future site of Bath-Haverhill Bridge
1829	Construction of Bath-Haverhill Bridge
1832	Claim for patent fees
1835	Ithiel Town's revised patent
1844	Death of Ithiel Town
1913	New Hampshire law requires bridges to be upgraded for ten-ton load
1921-22	Laminated arches added to Bath-Haverhill Bridge
1920s	Sidewalk added
1999	Bridge bypassed

## GEOGRAPHICAL DETAILS

The ancient covered bridge near the mouth of Ammonoosuc River at the north edge of Woodsville, New Hampshire is on the town line between Bath and Haverhill. The village of Woodsville forms part of Haverhill.<sup>1</sup> The bridge is known variously as Bath-Haverhill Bridge, or Haverhill-Bath Bridge, although some old accounts refer to it as Woodsville Bridge. The town boundary is a straight surveyed line beginning at a point on the nearby Connecticut River. By coincidence the line passes through the bridge site, although Ammonoosuc River is not the boundary. The two towns shared equally in the initial construction costs, but for several years at the beginning of the twentieth century, they disputed the exact boundary.<sup>2</sup> Bath-Haverhill Bridge was the first crossing on the site, and the only bridge here for 170 years.

## CONSTRUCTION OF THE BRIDGE

Inhabitants of Lyman and of Bath petitioned the Haverhill selectmen in 1826 to build a road along the Connecticut River, leading to the bridge over that river which gave access to Wells River, Vermont. Lyman and Bath had already put much effort into such a road, but the Haverhill link was missing. There was yet no mention of bridging the Ammonoosuc River. Later that year the Haverhill selectmen noted that they had laid out the road, but it appears that they only surveyed a right-of-way, without doing any construction.<sup>3</sup> From this point on, Haverhill records say very little. Many old New England town records relegated road and bridge matters to a separate Highway Surveyors' report, which is very often missing.

Fortunately the Bath records are more specific. In 1827 the town appointed a committee to meet with Haverhill to discuss a bridge site between the two towns.<sup>4</sup> At the regular Town Meeting in March 1828, Bath considered but rejected the bridge project, probably because the town already had more urgent expenditures for bridges elsewhere. A special meeting on September 29, 1828 did vote \$300 to purchase "stone & timber &

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<sup>1</sup> In the pronunciation of Haverhill the second H is silent.

<sup>2</sup> The matter is discussed in Bath Town Reports for the 1902-1908 period. Thanks to James L. Garvin of the New Hampshire Division of Historical Resources for bringing this to my attention.

<sup>3</sup> Haverhill Town Records, Vol. 3. From the section on marriages and petitions, not the Town Meeting minutes.

<sup>4</sup> Bath Town Records, Vol. 4, from the Town Meeting minutes, 1827-1839. Bridge detail is buried amidst other minutiae, and I missed the 1827 detail cited, but it is mentioned by other writers such as Richard G. Marshall, *New Hampshire Covered Bridges: A Link With Our Past* (Concord: New Hampshire Department of Transportation, 1994), p. 51. The following details come from the author's notes. The records at the New Hampshire State Library in Concord were the ones consulted.

other materials for building the Bridge across Ammonoosuck near Alcott's Saw Mill." This is the Bath-Haverhill Bridge site.<sup>5</sup>

Bath's March 1829 Town Meeting voted more money for the project and chose Ariel Miner to superintend for the town, but unfortunately there is no record anywhere of the builder's name. A special meeting on June 1, 1829 replaced Miner with Moses Abbot and Leonard Walker and voted "that the Selectmen be a committee to adopt the Moddle for building said bridge." This is significant for it means that the wooden trusswork was not yet built, although construction of the stonework may have begun late in 1828. Many older accounts give a date of 1827 for this bridge, and this date was posted on the portal for many years, but it is clearly in error. There are no further construction expenditures, so the work was probably completed in 1829. The total cost was about \$2,400 shared equally by the two towns.<sup>6</sup>

The selectmen were not as diligent as they should have been in studying the requirements for using their "moddle," for the Bath 1832 Town Meeting noted a claim of \$84 for right of building its 124' share of Bath-Haverhill Bridge according to Ithiel Town's patent.<sup>7</sup> The matter was referred to the selectmen for action, who probably paid it. Haverhill records are silent on this interesting problem. Town is reported as charging \$1 per linear foot for patent rights, or \$2 if rights were not secured in advance, so it is unclear what caused this charge of about \$.68 per linear foot.<sup>8</sup>

Haverhill records do contain a further petition for road work in 1832. The "Bridge near the mouth of Ammonoosuck River on the Narrows Road so called" was already there, but apparently Haverhill had still not completed the access road on its side. Several 1830s Bath Town Meetings charged the local highway surveyor with seeing that the bridge was "clear from being incumbered with Lumber or any thing else." Perhaps the nearby sawmill was using it as a convenient warehouse.

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<sup>5</sup> At the time, there was only a small hamlet around the sawmills at Woodsville; Bath and Haverhill were the principal villages.

<sup>6</sup> Rev. David Sutherland, *Address Delivered to the Inhabitants of Bath...With an Historical Appendix by Rev. Thomas Boutelle* (Boston: Geo. C. Rand & Avery, 1855), p. 73. However, Harold K. Davison, *Haverhill's Historic Highlights* (Littleton, NH: Courier Printing Co., 1963), p. 108, gives a figure of \$2,900.

<sup>7</sup> Article 11 on the warrant for the regular Bath Town Meeting in March 1832. The claim notes that the bridge was "to be built" according to Town's patent, but from previous sources it appears certain that it had been there since 1829. The language is a puzzle, but it may have been copied directly from an old invoice.

<sup>8</sup> Richard Sanders Allen, *Covered Bridges of the Northeast* (Brattleboro, VT: Stephen Green Press, 1957), p. 15, gives Town's rates. It is possible that a one-third payment was made up front, with the other two-thirds due upon completion of the bridge, but if so, why was such a straightforward business detail brought to the attention of Town Meeting?

## THE TOWN LATTICE TRUSS

Ithiel Town of New Haven, Connecticut (1784-1844) is best known as an architect who popularized the Greek Revival style. He designed state capitols, churches, and other prominent buildings, some of which are still in existence. He was also a major figure in the history of bridge engineering, because he developed the first completely new idea in truss design since the Middle Ages: the Town lattice truss.

Before Ithiel Town, long-span bridges were built either as arches, panel trusses, or some combination of both. All required large timbers and much custom joinery. The Town lattice truss used standard sawn plank in a repetitive pattern that could be built to any length, and made continuous over piers for added strength. It did not require complicated woodworking. There were no mortises, and it was held together by large wooden pegs called treenails, pronounced “trunnels” and sometimes spelled that way. Town also saw the possibility of using bolts at the joints.

Ithiel Town was working in North Carolina when he received his first patent in 1820. The plan called for a single lattice, with simple chords at top and bottom. Some sources say that Town specified an angle of 45 degrees between lattice planks and chords, but in fact he said “about 45 degrees or any angle that may be necessary for a brace (as they do the office of a brace).” It was designed to be covered, though he said it could also be built of iron.

Experience soon showed that the original Town lattice plan, though strong, was subject to warping. Town added secondary chords to correct this problem. He described them in 1820s literature, and included them in a revised patent in 1835 (No. X3169), which covered a doubled lattice. Although Town’s papers were lost in the Patent Office fire of 1836, he was still actively promoting his plan and was able to reconstruct the record.

Town built two covered bridges in North Carolina in 1818 and in 1819 that may have been prototypes for his lattice truss, plus one in Connecticut, his home state.<sup>9</sup> Apart from this he was a promoter of his “lattice mode” rather than a builder, deriving a substantial income from patent royalties. He also used a variant of his lattice for roof trusses in the First Presbyterian Church in Fayetteville, North Carolina, which still exists, and perhaps in other structures as well.<sup>10</sup>

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<sup>9</sup> On Town, see Allen, *Covered Bridges of the Northeast*, p. 15-16; also by the same author, *Covered Bridges of the South* (Brattleboro, VT: Stephen Greene Press, 1970), p. 3-5.

<sup>10</sup> Town lattice roof trusses are also reported in the Second Presbyterian Church at Madison, Indiana, apparently designed by Town and Davis in 1834. Town or his firm executed many other important commissions, including Federal Hall in New York City, and the North Carolina State Capitol at Raleigh. Some of these structures may have Town lattice roof trusses, and the question should be investigated. For a useful List of Town and Davis commissions, see Amelia Peck, ed., *Alexander Jackson Davis, American Architect, 1803-1892* (New York: The Metropolitan Museum of Art, 1992). Thanks to Richard Sanders Allen for bringing this source to my attention.

The Town lattice truss became a dominant style in covered bridges in the two areas where the inventor himself was active: New England, and the South. Later builders brought it elsewhere, and established regional traditions in other scattered areas. The Quebec Department of Colonization adopted a modified Town lattice for new regions it was opening to agricultural settlement from about 1890 onwards. In those regions it was still being built new as recently as 1955, well over a century after it was invented.<sup>11</sup>

The Town lattice truss is one of the most widely used forms of wooden trusses, along with the Burr and the Howe. It is a fine testimony to the American originality of its inventor.

## STRUCTURAL DETAILS

Bath-Haverhill Bridge is the earliest existing example of the Town lattice truss. It does have secondary chords, but otherwise was fairly simple as originally built, and does not show the structural refinements, which sometimes occur in later versions of the plan.<sup>12</sup>

All of the plank used for construction was nominally 3" x 10", although there is considerable manufacturing variation. Lattice web, primary chords, and secondary chords all use the same plank.<sup>13</sup> Chord planks are doubled on each side of the truss, which is the standard practice, for a total of four planks. All treenails measure 1-7/8" thick, with two per lattice joint, and three per chord joint.

The truss is 256'-0" long, and is continuous over the center pier. The two clear spans measure 104'-0" and 120'-9".<sup>14</sup> The housing extends another 8'-10-1/2" at floor level on the south end, and 12'-1-1/2" on the north, but is probably not original. The abutments and pier are of dry-laid cut stone.

However, the simple plan of Bath-Haverhill Bridge was much modified by the demands of the early twentieth century.

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<sup>11</sup> Several were built in the Abitibi region of northwestern Quebec up to 1954 and 1955. Reports of a bridge built in 1958 cannot be substantiated. The Quebec "colonization bridge" used spikes instead of treenails at the joints.

<sup>12</sup> Such as members roughly sized for the load. See reports on Brown Bridge, HAER No. VT-28, and Wright's Bridge, HAER No. NH-35.

<sup>13</sup> It was not possible to measure the lower primary chords, but they appear to be the same size as the other members.

<sup>14</sup> Marshall, p. 51, note 4, has the length of the clear spans, which I could not obtain without surveying equipment. His truss length of 256'-3" closely agrees with my measurement of 256'-0".

## REPAIR RECORD

By a 1913 act of the New Hampshire legislature, bridges were to be made safe for 10-ton loads after April 1, 1915.<sup>15</sup> This appears to have been an early case of unfunded mandate. It must have been a tremendous burden for small towns, and surely many did not comply.

In 1914, Bath sought the advice of John W. Storrs, a well-known bridge engineer from Concord. His reply was not encouraging. Bath-Haverhill Bridge was not “well-proportioned,” which may have meant that there was no effort to vary the timber size in accordance with the load. Moreover, it was “a pretty old structure” and was under high strain. Storrs requested more time to study the matter further.

The Woodsville Fire District again contacted Storrs in 1920 for advice on adding a sidewalk to the covered bridge.<sup>16</sup> He replied with an estimate, but clearly thought that the entire bridge should be replaced.

Instead, the towns decided to reinforce it with laminated arches. The work was done in 1921-22 for a cost for \$4,128.25 in materials and \$3,804.52 in labor. The total of \$7,932.77 was split evenly between the two towns. In addition, there were some expenses for road grading.<sup>17</sup> Based on structural evidence, the sidewalk seems to have been added at the same time, although one source says it was not built until after the 1927 flood.<sup>18</sup>

The arches are built up of sixteen leaves of plank, and they foot on shallow skewbacks chiseled into the old piers. They are intended to reinforce the entire truss, not just the floor system. Hanger rods support needle beams underneath the lower chords of the old truss, and an extension on the upstream side supports the sidewalk. Short cripple blocks stand upright on these needle beams and connect to the stringers of the old floor system, taking loads directly from the deck to the arches. However, the old floor beams are still in place atop the lower primary chords. They are probably not original, but they show evidence of very rough hand working, perhaps with a broadaxe rather than an adze. Another set of hanger rods relieves some of the strain from the old trusses by tying these old floor beams to the laminated arches.

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<sup>15</sup> Bath *Annual Report of the Town Officers* for 1915.

<sup>16</sup> Thanks to James L. Garvin of the New Hampshire Division of Historical Resources for providing copies of the 1920 Storrs correspondence with the Woodsville Fire District.

<sup>17</sup> Bath *Annual Report of the Town Officers* for 1922.

<sup>18</sup> Harold K. Davison, *Haverhill's Historic Highlights* (Littleton, NH: Courier Printing Co., 1963), p. 108, see note 6.



The designer of the arch system is unknown, but the sidewalk framing details differ considerably from those sketched by John W. Storrs in his 1920 estimate, so it was probably not he.

There are nine large floor stringers, but without ladders and staging it is impossible to measure them. They are much larger than usual for an old bridge, and are obviously not original. They rest atop the old floor beams, and are also supported by the short cripple blocks that foot on the new needle beams under the truss. The decking is transverse plank and is so worn that it is difficult to measure; inch-deep ruts are worn where the wheels passed for so many years.

## THE 1927 FLOOD AND RECENT REPAIRS

In November 1927, New Hampshire and Vermont suffered from a terrible flood. Hundreds of bridges and other riverside structures were swept away and destroyed. A large tree floated down Ammonoosuc River and punched a hole through the upstream side of Bath-Haverhill Bridge, destroying several lattice junctions, but the bridge held.<sup>19</sup> It was still a solid structure, despite engineer Storrs' doubts. New lattice planks were sistered in with bolts to repair the damage, and this work is evident today.

The 1920s also saw the establishment of the modern state highway network. The road through Bath-Haverhill Bridge received the designation New Hampshire Route 135, although the bridge was still owned by the two towns. At the time, there were many covered bridges on numbered highways, and some even carried U.S. route numbers.<sup>20</sup> By 1960 they had become scarce, but the Bath-Haverhill Bridge continued in daily service on Route 135 until a new bridge bypassed it in 1999, some 170 years after it was built.<sup>21</sup>

The bridge received repairs in 1973 to the tune of \$38,710, and \$8,000 more in 1981 to fix ice damage.<sup>22</sup> There was an arson attempt in 1983, and a sprinkler system was installed in 1998. For decades the bridge has also carried a water line laid along the sidewalk, and boarded over like a long bench.

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<sup>19</sup> *Historical Notes of Bath, New Hampshire 1765-1965* (Bath: Town of Bicentennial Committee, 1965), p. 73.

<sup>20</sup> Contrary to public perception, "U.S. Routes" are not federally owned. They are state highways with a uniform national numbering system.

<sup>21</sup> It was not quite the last covered bridge on a numbered highway. For example, at the time of this writing there are still covered bridges in service on numbered U.S. or state highways at Philippi, West Virginia (U.S. 250), and Jackson, New Hampshire (N.H. 16-A). There are also several on provincial highways in Canada.

<sup>22</sup> Marshall, p. 51.

Turning off U.S. Route 302 in Woodsville to go to the covered bridge, a low railroad underpass once served as an effective height barrier to keep heavy loads away. The rail line and underpass were removed in the early 1990s, and from that time on the old bridge itself was the only limitation to heavy traffic. It has been out of service since the bypass. The portal is closed with chain-link fence, although the sidewalk is still open (as of July 2002). It has been listed on the National Register of Historic Places since 1976, but is in much need of a sympathetic restoration that would preserve the original fabric of the truss. In June 2002 the selectmen of Bath and Haverhill voted for a restoration which would retain the laminated arches, and would raise the bridge 2' to protect against flood damage. As the oldest existing example of a Town lattice truss, Bath-Haverhill Bridge is a treasure of national significance.

**APPENDIX A: NOTES ON MATERIALS AND CONSTRUCTION  
TECHNIQUES OF BATH-HAVERHILL COVERED BRIDGE, BATH, NEW  
HAMPSHIRE to HAVERHILL, NEW HAMPSHIRE**

**James L. Garvin, New Hampshire Division of Historical Resources (STATE  
HISTORIC PRESERVATION OFFICE)**

**August 21, 2002**

The following notes are based on an inspection of the Bath-Haverhill Bridge on Saturday, August 17, 2002. The purpose of the inspection was to ascertain the amount of original fabric in the bridge, to study original construction methods, and to develop a sense of preservation priorities in the rehabilitation of the bridge. This inspection followed an arson attempt on the bridge, so the Haverhill police were notified of the inspection.

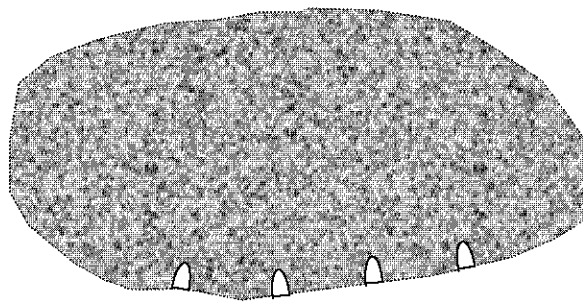
**Summary:** The Bath-Haverhill Bridge was built in 1829. It has thus far been documented in Brian Pfeiffer, National Register nomination (1974); in Hoyle, Tanner & Associates, "Engineering Study: Haverhill-Bath Covered Bridge, NHDOT Bridge No. 072/063, NH Covered Bridge No. 27, World Guide No. 29-05-04, Haverhill-Bath, New Hampshire" (June 2002); and in Joseph D. Conwill, "Bath-Haverhill Bridge," HAER No. NH-33 (July 2002). The following remarks will augment these studies with further observations made from the standpoint of an architectural historian.

The Bath-Haverhill Covered Bridge is the oldest Town lattice truss span remaining in the United States, and one of the oldest covered bridges to survive in the nation. It was built within nine years of Ithiel Town's first patenting of his lattice truss and, as Joseph Conwill has shown, the town of Bath was required to pay a royalty or a penalty for the use of Town's patent. The bridge was the first and remains the only span at this crossing between Bath and Haverhill (Woodsville), New Hampshire.

The Bath-Haverhill Bridge is a remarkable engineering document of the late 1820s. Its substructure, composed of two split granite abutments and one split granite pier, all standing on ledge, retains the flat-wedge splitting marks that are characteristic of granite quarrying before about 1830. Its superstructure retains a very high percentage of sawn lattice, chord, floor and roof members, all sawn from eastern white pine (*Pinus strobus*) on a water-powered upright or reciprocating sawmill. The framing techniques employed in the superstructure share certain characteristics with building frames of the same period. To compensate for irregularities in the planking that composes the bridge, a limited amount of hewing was employed to trim planks. To provide regular seats for rafters, tie beams, and diagonal wind braces, the carpenters borrowed techniques from the "square rule" method of framing, which had been newly introduced during the 1820s. In this carpentry technique, recessed seats were hewn in the faces of members to which other members are fitted. This ensures that all joints will be uniform and equidistant from reference lines despite surface irregularities in the intersecting timbers. The use of "square rule" framing has not previously been identified in a bridge.

**Substructure:** The substructure of the Bath-Haverhill Bridge is composed of two abutments of split granite, laid dry and not hammered to a true bed or face, and a central pier of the same material. Each of the three bridge supports stands on a bed of ledge that extends across the Ammonoosuc River at this point. During low water conditions, the northern or Bath abutment can be inspected along its full height, down to the underlying ledge. The southern or Haverhill abutment is partly submerged by the impoundment of a dam that extends diagonally across the river from the Bath side, intersects the central pier, and continues beneath the bridge at a different angle to a spillway and to a small hydroelectric plant on the Haverhill shore. The northern and western faces of the central pier can be inspected from the ledges below the dam on the Bath side of the river. The central pier has been pointed with mortar, much of which has fallen out of the joints over the years.

Many stones in the Bath abutment and the central pier reveal no obvious signs of the technology that was used to split them. A few stones in both the abutment and pier, however, reveal the presence of flat indentations along their edges. These indentations show that the granite was split using flat wedges inserted in narrow, elongated grooves or slots cut into the stone. This method of splitting granite persisted from the introduction of granite splitting technology in the 1770s until about 1830. After 1830, the flat-wedge method was superseded by the use of plug drills, which create a round hole in the stone, and by the use of “plugs and feathers,” which are wedges and shims that are shaped to fit into such round holes.



Evidence of flat-wedge splitting, pre-1830, as seen in stones in the north abutment and the central pier

Thus, the abutments and piers of the Bath-Haverhill Bridge reflect a pre-1830 granite-splitting technology. As will be shown below, the carpentry methods employed on the superstructure reflect technologies of the same period. Together, substructure and superstructure compose a single artifact that illustrates pre-1830 construction methods with a remarkable degree of preservation and integrity.

**Superstructure:** The trusses and floor and roof system of the Bath-Haverhill Bridge have been described in their overall form in both the Hoyle, Tanner and Conwill reports. The comments below discuss details of the carpentry of the bridge and relate those details to new methods of framing that were being employed in buildings during the 1820s. The

Bath-Haverhill Bridge is remarkable in illustrating the application to an engineering structure of practices common in architectural carpentry.

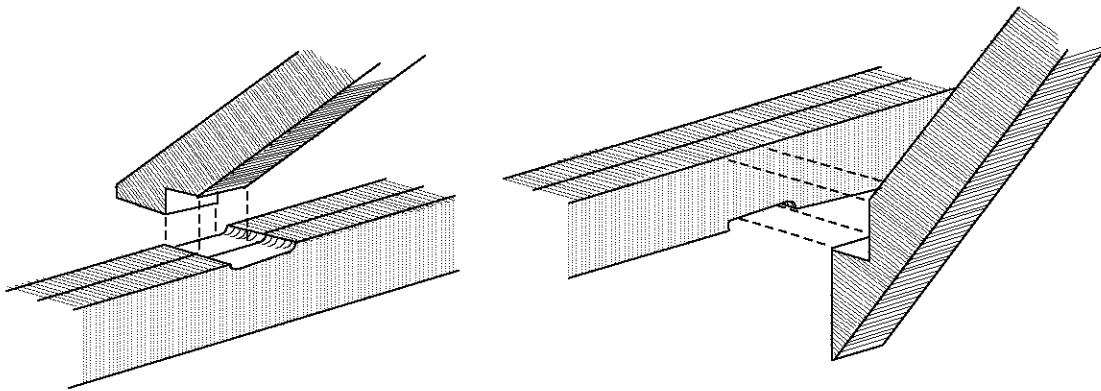
*Square Rule Framing:* Beginning in the 1820s, carpenters slowly abandoned the age-old method of framing buildings. In the older framing method, used in New England since first settlement, each mortise-and-tenon joint had been fashioned individually. To be certain that the surfaces of intersecting timbers fitted tightly at each joint, carpenters had scribed and chiseled the surface of the tenoned member against the surface of the mortised member. By this technique, the two intersecting surfaces fitted tightly when the tenon was inserted and pinned. This traditional carpentry technique was called the “scribe rule.” Because each joint in a scribe rule frame is unique, each of the two intersecting members was marked with the same incised numeral. These numerals ensured that the scribed joints could be assembled properly when the frame was moved from the carpenter’s yard to the site where the building was to be erected.

During the 1820s, carpenters moved toward a more standardized framing method. When using the new method, carpenters prepared patterns or templates for each type of joint in a frame, applying these patterns so that all mortises, tenons, pin holes, and other features of joints of the same type would be interchangeable. This method of providing identical and interchangeable joints was called the “square rule.”

Knowing that the timbers in a building frame might not be of exactly the same width and depth, even if sawn, carpenters applied their patterns with reference to lines drawn on each timber. By this method, each joint bore an identical relationship to others in the frame even if the timbers varied somewhat in their dimensions. Because the joints were uniformly related to reference lines on the timber, square rule framing required no incised numerals to ensure the proper assembly of mated members.

Square rule framing required that the seat of each joint be chiseled down below the irregular surface of the timber so that all seats would be equally distant from the lines drawn on the timber. The result is a noticeable cutting away of the outer surface of the timber at each joint—a clue that the carpenter was using the new, standardized framing method.

Square rule framing generally appeared in New Hampshire buildings during the 1820s. The same period saw an increasing use of sawn rather than hewn timbers in building frames. Sawn timbers did not always preserve a uniform dimension throughout their length, and they often twisted during seasoning, displaying “wind.” For these reasons, carpenters working with sawn timber frequently employed the square rule method of framing, chiseling seats below the surface of sawn timbers to provide identical intersections for mated members, just as they would have done if working with hewn timber.



Joint between rafter and Chord 1

Joint between wind brace and Chord 2

Introduction of the square rule method of framing coincided with an increasing use of common rafter roofs throughout northern New England. Such roofs often employed simple bird's-mouth joints where the rafters rest on the outer edges of the wall plates of buildings. In contrast to older methods of fastening rafters, these common rafters were often nailed to the wall plates through the V-shaped bird's-mouth cuts, using one or two large spikes.

*Framing techniques at the Bath-Haverhill Covered Bridge:* It is remarkable that evidence of the square rule framing method can be seen in the Bath-Haverhill Bridge. Even though the bridge employs sawn planks for its trusses, these planks are not altogether uniform in actual dimensions (see below, *Sawmilling technology*). For this reason, and probably out of habit as well, the carpenters who framed the bridge frequently provided hewn or chiseled seats at the intersection of two members.

Such seats may be seen in some cases where rafters or tie beams rest on the upper surfaces of Chord 1 (above diagram, left side). It is likely, though difficult to verify, that such seats were employed where the floor beams of the bridge rest on Chord 4.

In most cases, recessed seats are likewise seen where the feet of diagonal wind braces bear against the inner sides of Chord 2 (above diagram, right side). In these locations, an inverted, double-spiked bird's-mouth joint holds the foot of the brace against the bottom edge of the chord.

Given the practice of spiking the bird's-mouth joints at the feet of the wind braces to Chord 2, it seems likely that the rafter joints are similarly spiked to the upper edges of Chord 1.

*Sawmilling technology at the Bath-Haverhill Covered Bridge:* The Bath-Haverhill Bridge employed Ithiel Town's patent, a method of framing lattice trusses. One of the great advantages of Town's patent was its use of uniform, sawn planks, pinned together

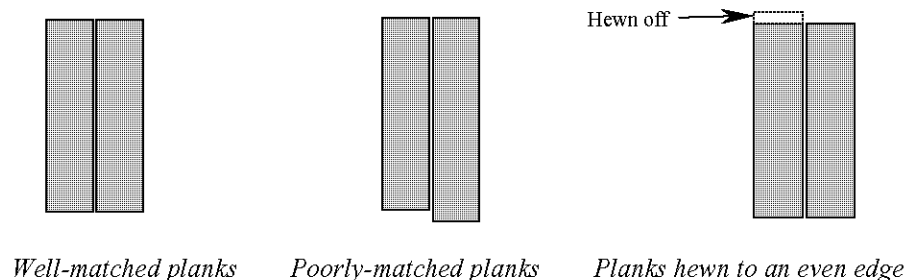
in a uniform, repetitive pattern, to create a truss as long as might be needed. Proponents of this simplified method of bridge construction reportedly described such trusses as capable of being “built by the mile and cut off by the yard.” Indeed, the ends of the trusses at the Bath-Haverhill Bridge do not terminate at vertical posts, but are simply “cut off,” with the ends of the diagonal lattice members unattached to anything.

In theory, a multitude of planks of a single dimension were sufficient to build a bridge according to Town’s patent. Such planks were pinned together at uniform angles to create the lattice, and others of the same type were pinned horizontally at the tops and bottoms of the lattice to create the upper and lower chords of the truss.

In the Bath-Haverhill Bridge, the standard plank dimension is 3” by 10.” All original planks seen in the bridge trusses, including those of the upper and lower chords, conform roughly to this dimension. All were sawn in upright or reciprocating water-powered sawmills.

In actuality, the average dimension of the truss planks seems to be about 3” by 9½.” Some planks measure as much as a full 10”, but many do not. The irregularity of plank widths may probably be attributed to inaccuracy in original sawing (see below), and also to shrinkage across the grain during seasoning.

In some cases, the planks that were paired to make elements of upper chords were mismatched in width. If it was important that the edges of these paired planks be even, as where rafters rest on the tops of the uppermost chords, the projecting edges of the wider planks were carefully hewn off (right diagram, below). In other cases where it did not matter, the paired planks were made even at top or bottom, but allowed to have staggered edges on the opposite side (middle diagram, below).



The difficulties of obtaining uniform planks from local sawmills may reflect the imprecision with which reciprocating sawmills normally produced lumber. Since the Bath-Haverhill Bridge was built in an age when carpenters often reworked rough lumber with planes and other finishing tools when they needed uniform dimensions or finished surfaces in a building, the production of planks of perfect uniformity was perhaps not demanded or expected of sawmill operators.

The New Hampshire law regarding sizes of boards and planks that was in effect in 1829 had been passed by the legislature in 1785. It stated that “no pine boards shall be shipped

for exportation to a foreign market but such as are square edged, and *not less* than one inch in thickness [*italics added*].” Regarding plank thickness, the law stated, “the standard for the thickness of merchantable plank shall be two inches; and when any shall be purchased for particular use, of different thickness, it shall be admeasured and calculated by that standard.”<sup>23</sup> This law implied that every merchantable board or plank of a given nominal thickness was required to have at least the thickness cited. The law did not forbid sawing boards or planks somewhat thicker than the nominal dimension, and some of the planks used in the truss webs and chords of the Bath-Haverhill Bridge are somewhat over three inches in thickness. As with the varying width of the planks in the trusses, this variation in thickness appears to have been unintentional but within tolerances that were acceptable at the time.

One remarkable feature of the Bath-Haverhill Bridge is the degree to which original planking has survived throughout the structure. Except where the eastern truss was damaged by a floating tree in the flood of 1927, there are few places where 3” by 10” planks, showing the distinctive marks of the reciprocating saw, are not found throughout the structure. Indeed, even the bottom chords (Chords 3 and 4), most exposed to spray from the dam below, show this evidence of great age in those areas where they can be observed.

It was possible to examine one floor joist or beam at close range at the central pier of the bridge. Although covered with friable, fuzzy wood fibers raised by road salt and moisture, this beam proved to be very sound and to reveal the marks of a reciprocating sawmill. Although it was impossible to examine other joists as closely, their appearance when seen from below suggests that many of these members are similarly sawn, and so may be very old if not original to the bridge.

As noted by Joseph Conwill in his report, most of the bridge’s floor joists appear to have been hewn on their bottoms. Although these timbers could have begun as logs that were hewn to a single flat surface before first being run through a sawmill, they could also derive their rough-hewn bottom surfaces from a more recent attempt to chop away the fuzzy fibers that may have formed on their undersides.

It is remarkable that almost all of the tie beams, upper lateral bracing, and rafters of the bridge also show evidence of having been sawn on an upright saw. The same is true of most of the roof sheathing boards, which run longitudinally from rafter to rafter; only the roof sheathing close to the eaves of the bridge reveals a large proportion of replaced boards. The majority of diagonal wind braces, which link the rafters to the tie beams and to the bottom of Chord 2, have been replaced due to breakage from truck impact or to the insertion of the arches in the bridge, yet a few upright-sawn originals remain. In such cases, the diagonal wind braces are pinned to the tie beams and rafters with square or square-headed wooden trunnels.

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<sup>23</sup> *The Laws of the State of New-Hampshire* (Hopkinton, NH: Isaac Long, Jr., 1830), Title L: “Admeasurement and Size of Lumber,” Chapter I, pp. 212-216.



Although a closer survey of the bridge may reveal more new wood than was apparent in our inspection, it appears that the Bath-Haverhill Bridge retains a percentage of original materials that would be considered high even in a surviving dwelling of 1829. This is doubly remarkable because the bridge is exposed to harsh and damp environmental conditions and traffic impacts, and because it is one of the oldest wooden bridges in the United States. The high proportion of surviving original fabric, combined with unexpected evidence of framing techniques of the 1820s that have not previously been noticed in a bridge, make the Bath-Haverhill Bridge a remarkable and valuable monument in the history of American engineering.

## APPENDIX B: ENGINEERING REPORT

### Introduction

The Bath-Haverhill Bridge is the oldest Town lattice truss bridge still in existence. Built in 1829, the original structure was augmented almost a century later with laminated arches to meet increased load requirements. The purpose of this study is to investigate the original behavior of the truss and to evaluate its present performance in relation to the later modifications.

### Characteristics of the Bath-Haverhill Bridge

The original bridge was built using a continuous Town lattice truss over a central pier, forming two spans of approximately 135' and 121'. The height of the truss is 13'-6". The truss members display evidence of having been cut in a sawmill instead of being hand-hewn. The bridge was modified in 1920/21 when laminated arches measuring 10 x 33" in section were added, along with a new suspended deck and a sidewalk cantilevered on extended floor beams on the northeast (upstream) side.

The primary and secondary upper and the lower chords are each approximately 12 x 10" in section and consist of sistered planks. They are doubled, with the lattice sandwiched between them. The 1921 rehabilitation added reinforcements at key splices. The lattice (web) planks are nominally 3 x 10". Most of these structural features, along with some temporary bracing cables, are visible in Figure 1.



Figure 1. Interior view of Bath-Haverhill Bridge. Field photograph.

The connections between diagonals were made with dual, 1 7/8"-diameter treenails aligned vertically, while the connections with the chords were made with three of these same treenails in a triangular array (Figure 2). The majority of the treenails, which are all presumed to be original, have wedges driven into slots cut across their nose ends (the

ends opposite their heads). It is not known when the wedges were installed, and it may well have been at different times, but they were likely introduced to counteract shrinkage in the diameter of the treenails and, thus, retighten the connections (Figure 3).

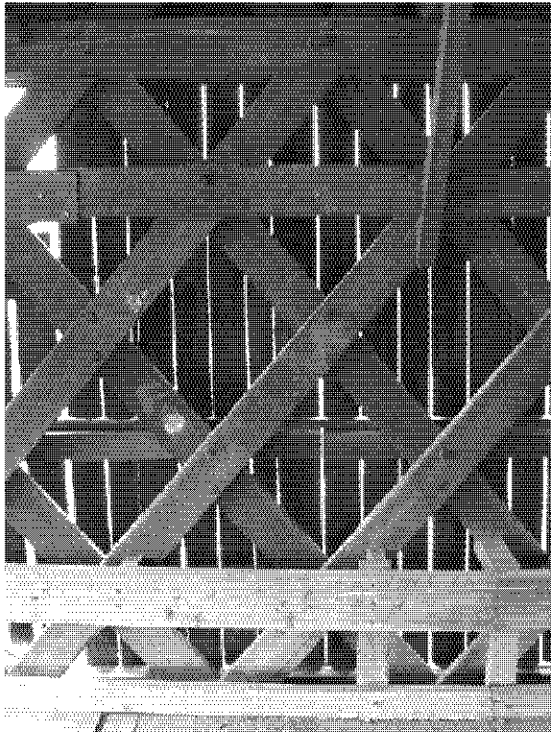


Figure 2. Internal view of the truss. Field photograph.

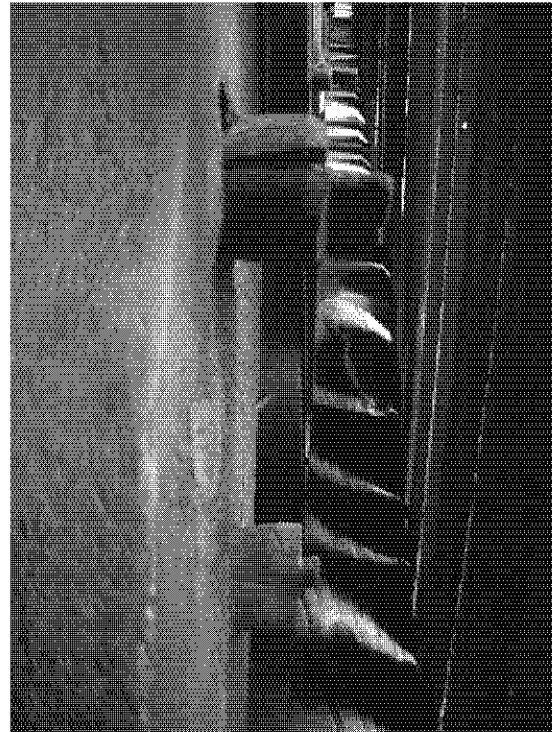


Figure 3. Detail of wedges in treenails. Field photograph.

The woods used to build the original bridge were, not surprisingly, identified as local species. Eastern white pine was the builder's choice for structural members, while the treenails, which needed to be a denser, stronger wood, were made of white oak. The original deck and supporting structure was likely eastern white pine as well, but Douglas fir was the primary material used in the bridge's 1921 rehabilitation, particularly for the laminated arch and chord-splice pieces. By this time, the transportation infrastructure allowed the economical use of a wood that, although very suitable for the application, did not grow in the area.

The arches have sixteen plies, and they foot on shallow skewbacks chiseled into the old piers. They were not intended to interact with the truss alone, as in a Burr arch-truss, but rather to relieve the truss of a portion of the deck and live loads. Every other floor beam, interestingly referred to as a "needle beam" in this bridge, hangs on metal rods from the central portion of each arch. These new needle beams were installed under the lower primary chords at the same time as the arches, and they have extensions to support the sidewalk. Short cripple blocks stand upright on these needle beams and connect to the stringers of the old floor system, to take loads directly from the deck to the arches. Older needle beams alternate with the new ones. These, however, rest on the lower primary

chords, but they, too, now have hanger rods to the arches. These may not be original timbers, but they do show evidence of very rough hand working, perhaps with a broad axe rather than an adze.

There are nine large floor stringers, but without ladders or scaffolding it was not possible to measure them during the July 2004 inspection. They are much larger than usual for a bridge of this age and obviously are not original. They rest atop the old needle beams, and are also supported by short cripple blocks that bear on the new needle beams under the truss. The decking consists of transverse planks, and it is so worn that it is difficult to determine the original plank dimensions. Inch-deep ruts have been worn into the wood.

### **Structural analysis of the Bath-Haverhill Bridge**

While it is possible to make some basic calculations of the Bath-Haverhill Bridge's structural performance, a precise determination of its performance characteristics would be extremely difficult to do for several reasons. Any Town lattice truss is a structure with multiple redundancies in its chords and web, making it statically indeterminate. The use of more-complex models that include individual-member deflections and their role in force distribution throughout the structure can theoretically overcome this limitation, but several key assumptions about joint conditions would still be required. The additional redundancy of the arches added in 1921 make the situation more complex still, since each span of the bridge now actually consists of two largely separate, but interacting bridges (lattice truss and arch) that each carry an unknown portion of the total load.

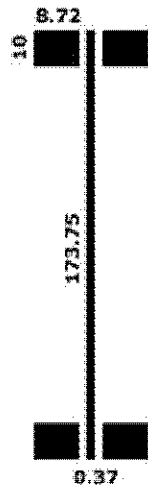
Even with these limitations, some approximate, but still useful, theoretical understanding of this bridge can be gained. The approach herein will be to first examine the truss and arch separately.

A classic method for analyzing a Town lattice truss is to consider it as equivalent to a beam and assume that its web has the same mechanical properties. Modern finite element analysis (FEA) software provides an alternate analytical method. Using both methods and comparing their results should provide some degree of confidence in the underlying assumptions and the results obtained.

## **ANALYSIS OF THE TRUSS**

### **Equivalent Beam Method**

A homogeneous beam equivalent to the truss structure is shown in Figure 4, along with its significant mechanical properties.



Weight ( $W$ ) of the equivalent beam = 18,582 lb  
(unit weight of white pine = 0.0147 lb/in<sup>3</sup>)

Area ( $A$ ) of the section = 413.09 in<sup>2</sup>

Volume ( $V$ ) of the equivalent beam = 1,264,055 in<sup>3</sup>

Moment of inertia ( $I$ ) of the section = 2,341,015 in<sup>4</sup>

Figure 4. Equivalent beam for Bath-Haverhill Town lattice truss

The following assumed live loads were used:

$$\text{Deck surface area} = 3060 \times 281.75 = 862,155 \text{ in}^2$$

$$\text{Snow load per inch} = 0.417 \times 862155 / (3060 \times 2) = 58.74 \text{ lb/in per truss}$$

$$\text{Pedestrian load per inch} = 0.59 \times 862155 / (3060 \times 2) = 83.12 \text{ lb/in per truss}$$

No vehicle load was included, as the bridge has been closed to vehicular traffic since 1999.

Table 1 contains the calculated deflections for the two spans from the equivalent beam analysis. Negative numbers indicate downward deflections.

Table 1. Equivalent beam deflection analysis

	135-ft Span Deflections (inch)			121-ft Span Deflections (inch)		
	¼ span	½ span	¾ span	¼ span	½ span	¾ span
<b>Dead Load</b>	-2.75	-3.67	-2.75	-2.16	-2.89	-2.16
Dead + Ped. Load	-9.32	-12.44	-9.32	-7.34	-9.79	-7.34
Dead + Snow Load	-7.97	-10.64	-7.97	-6.28	-8.37	-6.28
Dead + Live Loads	-14.54	-19.41	-14.54	-11.45	-15.28	-11.45

### Finite Element Method

A finite element model was designed to replicate the Bath-Haverhill Bridge using the SAP 2000 structural analysis software package. The same dead and live loads used in the equivalent beam analysis were used for consistency. Figure 5 is a graphical depiction of

the bridge's deflection (exaggerated in the vertical direction for clarity). The overall shape matches that expected for a continuous truss across a central pier, and the shape at each end is consistent with the bolster-beam supports that exist on this bridge.



Figure 5. Finite element plot of deflection (vertical scale exaggerated)

Table 2 contains the calculated deflections for the two spans from the finite element analysis. Negative numbers indicate downward deflections.

Table 2. Finite element beam deflection analysis

	135-ft Span Deflections (inch)			121-ft Span Deflections (inch)		
	¼ span	½ span	¾ span	¼ span	½ span	¾ span
<b>Dead Load</b>	-1.40	-2.17	-1.053	-0.58	-1.54	-0.87
Dead + Ped. Load	-2.19	-3.16	-1.47	-1.08	-2.24	-1.33
Dead + Snow Load	-1.76	-2.94	-1.3	-0.9	-2.02	-1.19
Dead + Live Loads	-2.48	-4.03	-2.14	-1.35	-2.61	-1.65

A comparison of the average deflections for each load condition is shown in Table 3.

Table 3. Comparison of average deflections calculated by equivalent beam and finite element analytical methods, calculated as follows:

$$\text{percent} = (\text{finite element average} / \text{equivalent beam average}) \times 100$$

	135-ft Span	121-ft Span
<b>Dead Load</b>	50.0 %	41.0 %
Dead + Ped. Load	22.0 %	19.0 %
Dead + Snow Load	22.5 %	19.6 %
Dead + Live Loads	17.8 %	14.7 %

The greatest stresses and moments calculated by the finite element analysis method are shown in Table 4. These are the highest tension stresses, compression forces, or moments in any member of each type listed, not the magnitude in every member of the same type. Positive numbers indicate tension forces and negative numbers indicate compression forces. (1 kip = 1,000 pounds force)

Table 4. Maximum stresses and moments from finite element analysis

Dead Load			
	Max. Positive Axial Force (kip)	Max. Negative Axial Force (kip)	Max. Moment (kip-in)
Web members	24	-36	25
Chord	118	-160	25
Middle chord mom.			225
Dead + Pedestrian Load			
	Max. Positive Axial Force (kip)	Max. Negative Axial Force (kip)	Max. Moment (kip-in)
Web members	41	-58	30
Chord	159	-233	30
Middle chord mom.			213
Dead + Snow Load			
	Max. Positive Axial Force (kip)	Max. Negative Axial Force (kip)	Max. Moment (kip-in)
Web members	34	43	28
Chord	147	-221	27
Middle chord mom.			216
Dead + Live Loads			
	Max. Positive Axial Force (kip)	Max. Negative Axial Force (kip)	Max. Moment (kip-in)
Web members	188	-258	33
Chord	54	-75	34
Middle chord mom.			211

These results show quite clearly the limits of the equivalent truss model. The lattice truss behavior changes strongly in relation to the load, the total length of the span, and the load applied. Just considering the deflections of each span at a time, it is evident that the behavior of the structure more closely approaches that of a beam as the load increases. This is even more evident when one recalls that the deflection is a function of the moment in the equivalent beam method.

### Analysis of the Arch

A technique similar to that used for the equivalent beam also was used for the arches. As with the equivalent beam, the live loads were converted to multiples of the equivalent beam dead load.

For the 135'-span arch:

Multiplier for dead + pedestrian load = 49.31

Multiplier for dead + snow load = 41.91

Multiplier for dead + live (pedestrian + snow) loads = 77.96

For the 121'-span arch:

Multiplier for dead + pedestrian load = 56.21

Multiplier for dead + snow load = 47.77

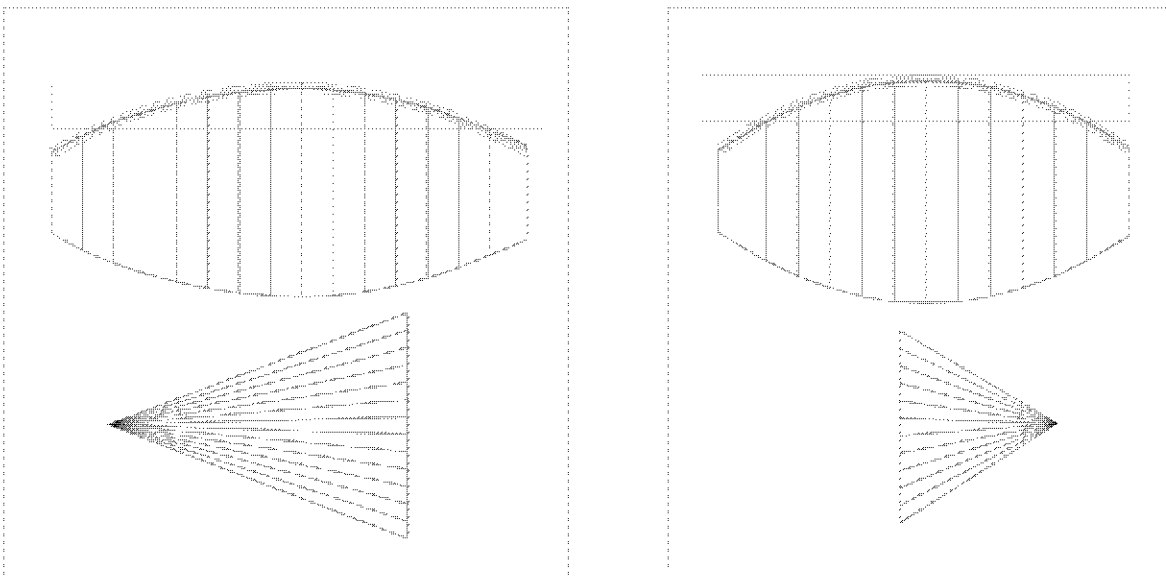
Multiplier for dead + live (pedestrian + snow) loads = 88.87

Table 5 contains the calculated deflections for the two spans from the arch analysis. Negative numbers indicate downward deflections.

Table 5. Arch deflections

	135-ft Span Deflections (inch)			121-ft Span Deflections (inch)		
	¼ span	½ span	¾ span	½ span	¼ span	¾ span
<b>Dead Load</b>	-0.000981	-0.00144	-0.000951	-0.000733	-0.00101	-0.000706
Dead + Ped. Load	-0.00345	-0.00507	-0.00338	-0.00274	-0.00379	-0.00264
Dead + Snow Load	-0.00166	-0.00243	-0.00162	-0.00231	-0.00320	-0.00223
Dead + Live Loads	-0.00542	-0.00796	-0.0053	-0.00430	-0.00595	-0.00414

These simplified calculations indicate that the difference between the two deflections is of the order of 500 times. In reality, the difference between the two behaviors is not as dramatic, but it is nevertheless clear that the arches are carrying most of the load in both spans. Graphical analysis confirms this, as shown in the curves of pressure for the two arches in Figure 6. The line of the pressure for distributed loads passes through the central third of the arch.



(a) Curve of pressure for the 135-foot span      (b) Curve of pressure for the 121-foot span  
Figure 6. Curves of pressure for arches



Using the distributed loads used in the graphical analysis of the arch yields the axial forces at the ends of the arches shown in Table 6.

Table 6. Axial stresses at ends of arches

Abutment End 135-foot Span	Central Pier End 135-foot Span	Central Pier End 120-foot Span	Abutment End 120-foot Span
1.435 kip/inch <sup>2</sup>	1.452 kip/inch <sup>2</sup>	0.847 kip/inch <sup>2</sup>	0.863 kip/inch <sup>2</sup>

### Dead Load Calculations

#### Dead load of roof per inch:

$$\text{Transversal beams} = 9 \times 5 \times 281.75 \times 31 \times 0.0147 / (3060 \times 2) = 0.94$$

$$\text{Diagonals} = 6.25 \times 11.25 \times 210 \times 52 \times 0.0147 / (3060 \times 2) = 1.84$$

$$\text{Rafters} = 3.5 \times 5.75 \times 100 \times 62 \times 0.0147 / (3060 \times 2) = 0.3$$

$$\text{Roof boards} = 1 \times 862155 \times 1.085 \times 0.0147 / (3060 \times 2) = 2.25$$

$$\text{TOTAL} = 0.94 + 1.84 + 0.3 + 2.25 = 5.33 \text{ lb/in}$$

#### Dead load of deck per inch:

$$\text{Transversal beams} = 9 \times 5 \times 281.75 \times 31 \times 0.0147 / (3060 \times 2) = 0.94$$

$$\text{Diagonals} = 6.25 \times 11.25 \times 210 \times 52 \times 0.0147 / (3060 \times 2) = 1.84$$

$$\text{Longitudinal stringers} = 5 \times 13 \times 9 \times 3060 \times 0.0147 / (3060 \times 2) = 4.3$$

$$\text{Upper layer} = 5 \times 862155 \times 0.0184 / (3060 \times 2) = 12.96$$

$$\text{TOTAL} = 0.94 + 1.84 + 4.3 + 12.96 = 20.04 \text{ lb/in}$$

#### Dead load of the truss per inch:

$$\text{Chords} = 3.5 \times 10 \times 3060 \times 16 \times 0.0147 / 3060 = 8.23$$

$$\text{Lattice} = 2.75 \times 10 \times 229.25 \times 128 \times 0.0147 / 3060 = 3.88$$

$$\text{Treenails} = 3.14 \times 1 \times 0.027 \times 18 \times 128 / 3060 = 0.06$$

$$\text{Boards} = 1 \times 98 \times 0.025 = 2.45$$

$$\text{TOTAL} = 8.23 + 3.88 + 0.06 + 2.45 = 14.62 \text{ lb/in}$$

$$\text{TOTAL DEAD LOAD} = 5.33 + 20.04 + 14.62 = 39.99 \text{ lb/in}$$

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